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U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Fuel Cycle Technologies

FCRD Ceramic Fuels Development Overview

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Briefings for JAEA Survey Visit

Los Alamos National Laboratory

December 10, 2014

LA-UR-14-xxxx

Outline

- **Ceramic Fuels Technology Overview**
  - Overall context and past activities
  - Current Objectives, approach, and requirements
  - FY15 overview of scope and effort summary
  - FY15 Integration (Interfaces/collaborations)

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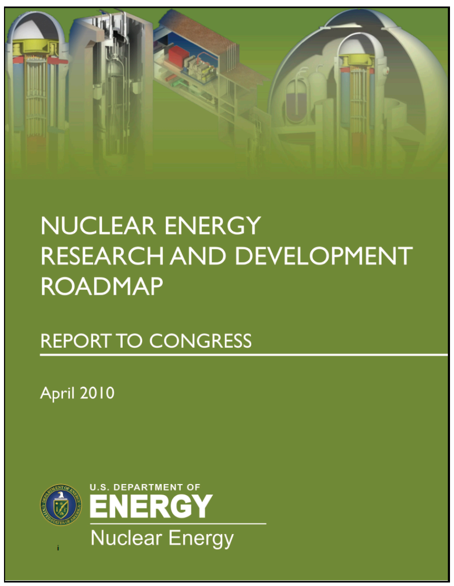
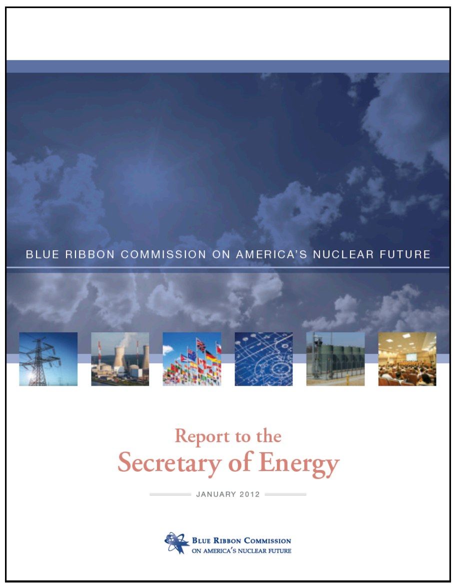
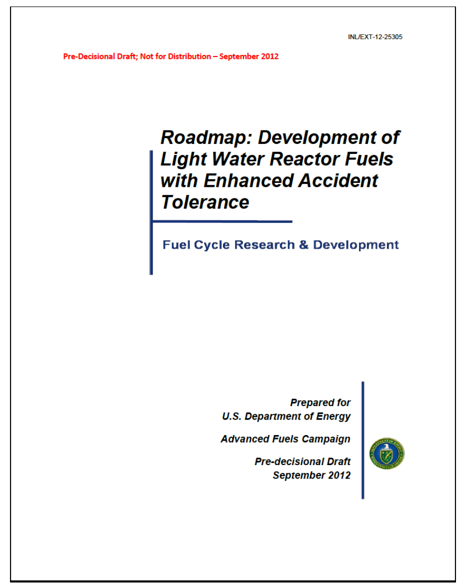
Fuels priorities change but the science-based R&D approach remains the focus

A goal-driven, science-based R&D approach enables improved fundamental understanding which in turn supports development of predictive fuel performance models and accelerated development of advanced fuels.







DOE will continue to explore advanced concepts in nuclear energy that may lead to new types of reactors with further safety improvements and reduced environmental and nonproliferation concerns. –DOE Strategic Plan 2014-2018

Ceramic Fuel Scope, Objectives and Approach

- **Scope: Result-oriented, science-based ceramic fuels R&D that supports advancement of nuclear power in the US**
  - LWR and Transmutation Fuels (thermal and fast spectrum)
    - *Pellet forms (<u>oxide,</u> nitride, carbide, IMF and dispersion fuel types)*
    - *Has included targets*
    - *Does not include coated particles*

- **Objectives: Explore and develop ceramic fuel technologies that further improve safety and that reduce environmental concerns**

- **Graded material system approach to enable efficiency and involvement of international and university partners**
  - surrogate →DU/Th →LEU/HEU →TRU

BNL/ORNL **LANL** **INL**

Design → Process → Properties → Performance

International/Universities

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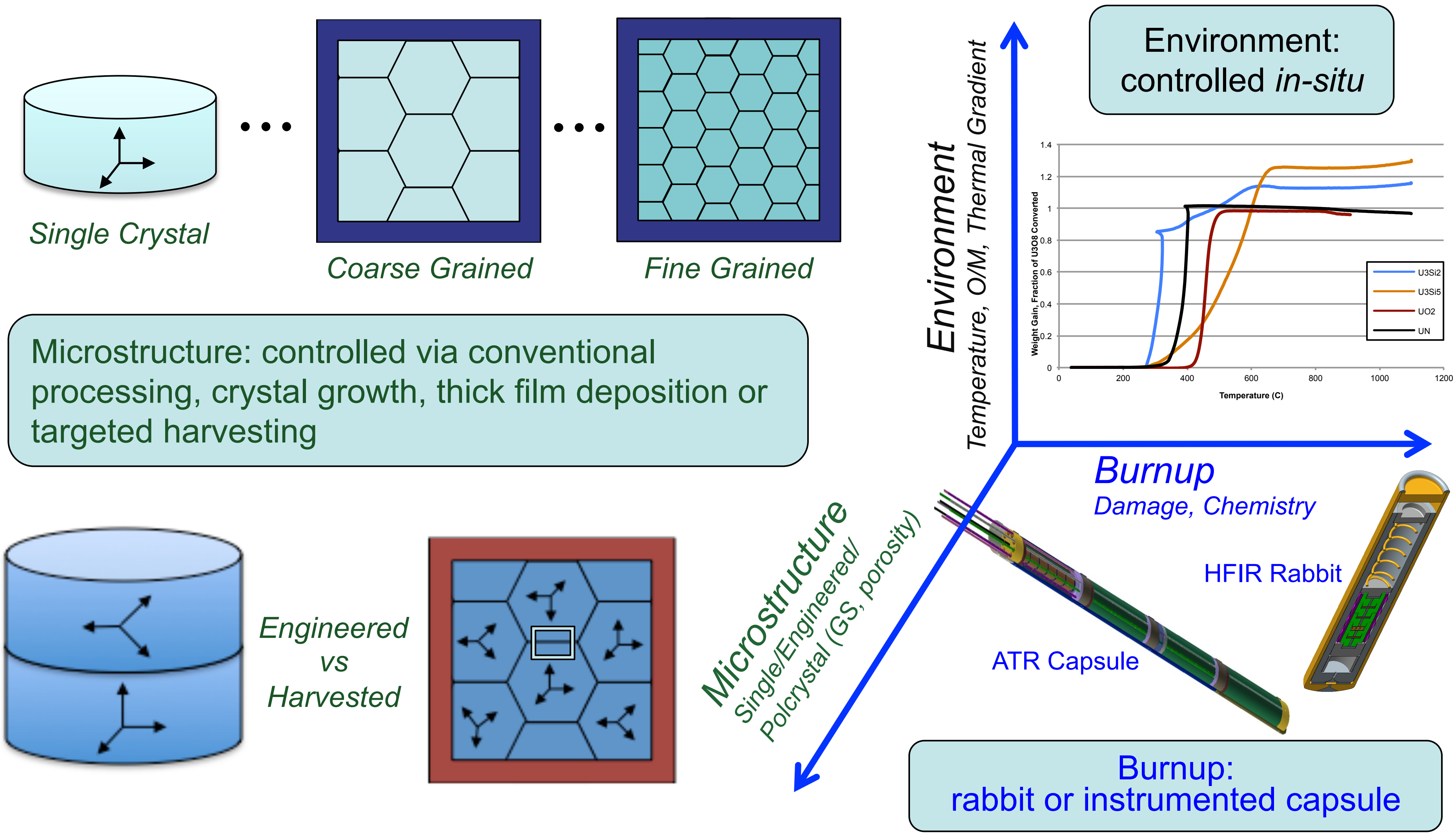
Key Ceramic Fuel Objectives (FY15)

- **Enhance the performance and safety of LWR fuel systems**
  - Assess and develop enhanced UO_2 and Advanced Ceramic Composite concepts
  - Develop fuel oxidation (accident behavior) knowledge
    - *Including the ability to predict and mitigate impact of advanced clad development on the ceramic fuel*
- **Transmutation Fuels**
  - Support fabrication and characterization at INL
- **Improve performance understanding and predictive models**
  - Continue development of advanced characterization techniques to improve the efficiency of fuel development and licensing process to get more out of less via improved data sets and support of predictive modeling
  - Assess and develop advanced fuel manufacturing technology that can enable new advanced fuel concepts
  - Continue fundamental studies on key performance characteristics to underpin evolutionary and revolutionary advances in ceramic fuels, including the enhancement to accident tolerance
    - *SET testing*
    - *Reference material synthesis*

Nominal SET experimental parameter matrix



FY15 Ceramic Fuel Activities (FY15 Continuing Resolution budget)

- **Advanced LWR Fuels**
  - Advanced Accident Tolerant Ceramic Fuel Development
    - *Enhanced UO_2 Fuels (LANL/ASU)*
    - *Advanced Ceramic Composite Fuels (LANL/BNL/ORNL)*
    - *High temperature properties/accident behavior (LANL/JAEA - CNWG)*
  - Advanced Technique & Fuel Material Development
    - *Advanced PIE (LANL/INL - CNWG)*
    - *Field Assisted Sintering (LANL - NEUPs & EURATOM I-NERI)*
    - *Reference Materials (ORNL)*
    - *Technical Integration (NEUPs, CNWG, SFR-AF, EURATOM I-NERI, etc)*
  - *Fabrication of Enriched Ceramic Fuel*
    - *ATF-1 LANL-1 and LANL-2 Fuel Fabrications (LANL)*

Approach and Requirements for Development of Ceramic Fuels With Enhanced Accident Tolerance

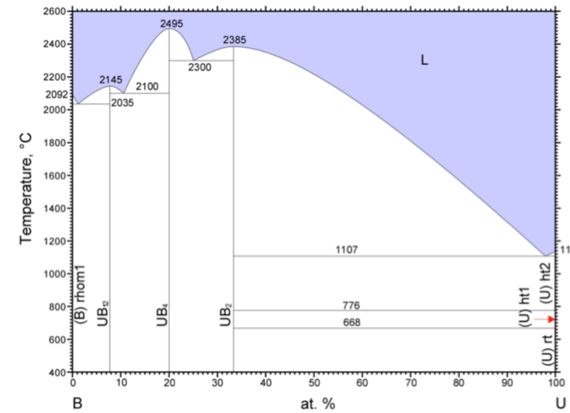
- **Approach:**
  - Develop ceramic fuels with at least comparable performance under all conditions, and improved performance in accident scenarios → fuel can enable cladding change (while maintaining/increasing linear power)
  - Develop fabrication and evaluation techniques that can enable new fuels and can enable accelerated development
- **Preserve/Improve Characteristics for Normal Operation:**
  - Burnup/Cycle length (criticality, fuel performance)
  - Operations (power distribution, peaking factors, margins, etc.)
  - Reactivity coefficients and control (shutdown margin, rod worths)
  - Handling, transportation, storage (isotopics, dose)
  - Compatibility with infrastructure (economics)
- **To warrant the label of "ATF" enhanced system must <u>improve response to transients/accidents while at least maintaining performance under normal operating conditions</u>:**
  - Anticipated Operational Occurrences (AOOs)
  - Design Basis Events (LOCA, RIA)
  - Beyond Design Basis Events (Fukushima)

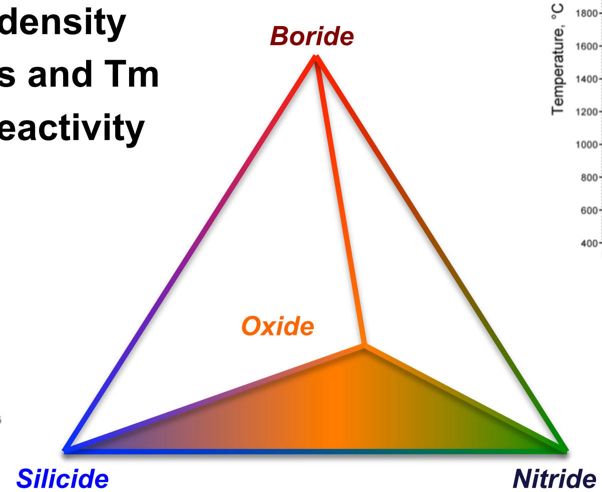
Advanced Ceramic Fuels Development Constraints

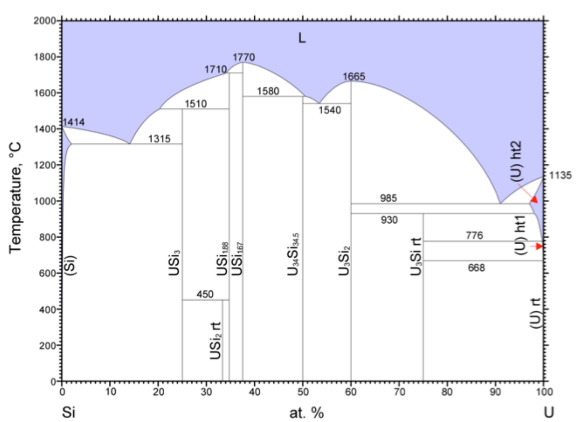
- **Constraints:**
  - Compatibility with new ATF cladding
  - Must be economical
    - *Lower fuel cycle cost, "Low cost" manufacture, High power, Deeper burn*
  - Minimize deviation from existing infrastructure, experience and expertise
    - Consider enrichment increases in stages: e.g. <5, 5-7, 8-10, <20%
    - Similar/same infrastructure: UF_6 source, open powder processing or MOX-type line
- **Target key performance aspects**
  - Increase thermal conductivity
  - Increase toughness/engineer cracking
  - Oxidation and coolant compatibility at least as good as UO_2 (in new cladding)
  - Maintain current cycle length and performance while enabling cladding changes
  - Allow at least similar reactor operation
- **New accident tolerant LWR fuel will likely be a composite with at least two discrete phases**

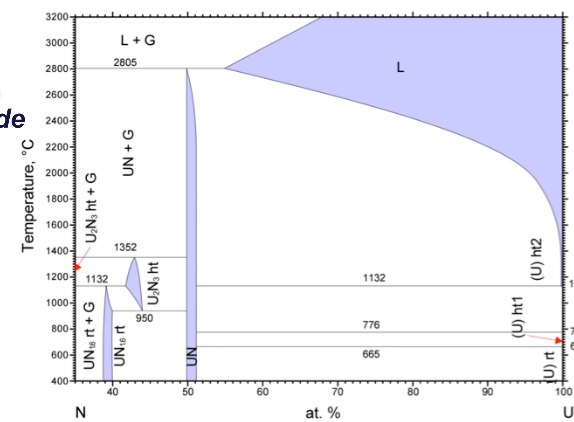
Fuel Development: Composite Ceramic Fuels

- **Engineering a ceramic fuel via a composite approach enables industry to utilize existing infrastructure (or at least mitigates deviation from their capabilities and experience base)**
- **Design via high fissile density (U-based) constituents can enable low(er) enrichments relative to conventional composite (inert matrix) fuel concepts**
- **Advanced ceramic fuels will have performance benefits and can enable cladding changes**
- **Aluminides rejected for fissile density**
- **Ferrides rejected for neutronics and Tm**
- **Carbides deprioritized due to reactivity**









Technique Development: LANSCE-based advanced, nondestructive Pre- and Post-Irradiation Examination

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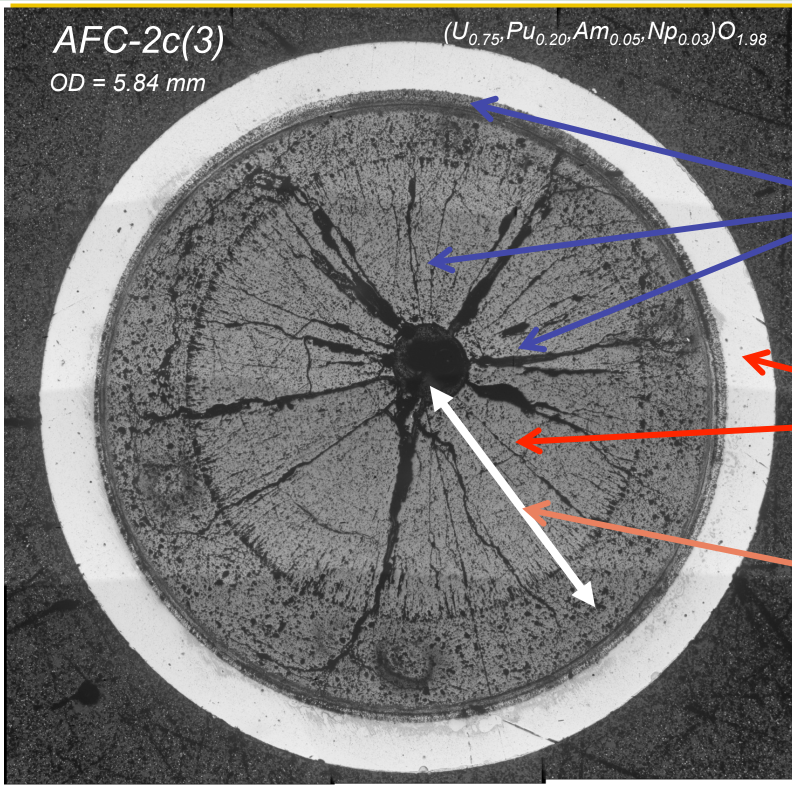
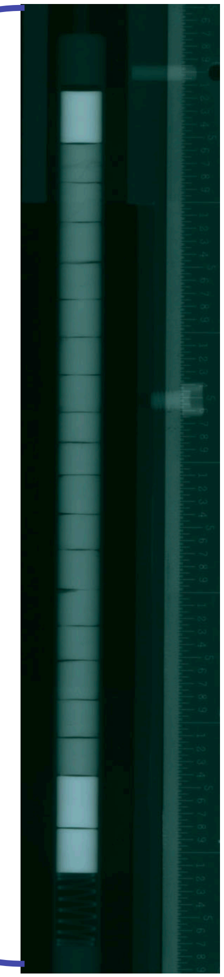


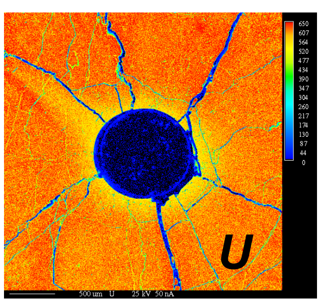
NDE of interest

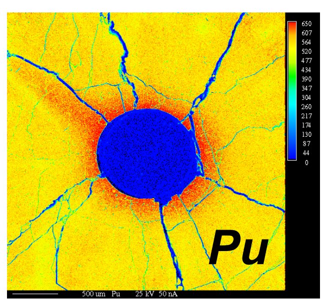
n, p-radiography/tomography
Voids, cracking, gap, clad thickness, density, bubbles

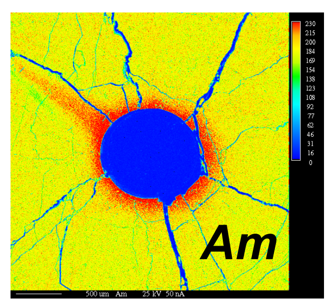
Bragg Diffraction
Phase distribution, strain

n resonance tomography
Species (e.g. FG, MA, Ln) distribution









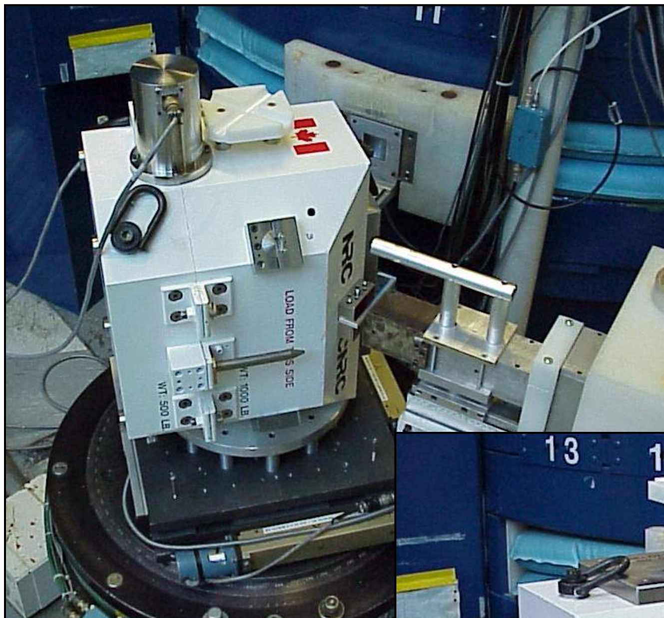
Am-1 Program
Joyo B-11(2) Test
-P601252, 42.7 kW/m
-5wt%Am, Pu29wt%
-O/M = 1.95
- 24 hours
-X/L = 0.49

*Tanaka et al., JNM **440** (2013)*

Specially Designed Shielded Container for beamline handling: Example from Chalk River/AECL/CNRC

Transportation to and within LANL is probably the major constraint. Dose and quantities are not limiting for a couple of rodlets at a time.

- Sample, main source is ^{60}Co
- 200 Sv/h (20 000 R/h) on contact
- Analysis gave 1.4 TBq on most active sample



Longitudinal

Transverse

- *12.7 cm (5") Pb path*
- *Weight, 682 kg (1,500 lbs)*
- *Shield, 20-40 μSv/h (2-4 mR/h) on contact*
- *Through ports, 2-10 mSv/h (0.2-1 R/h) at exit*
- *No impact on ^{3}He detector*

Images and numbers from Ron Rogge

Advanced PIE approach

We must utilize current capabilities in a new way

ATF-1

Advanced, Integrated - PIE

Testing	*ATR*
HFEF	*Initial fuel assessment; package & ship to LANSCE*
LANSCE	*Advanced NDE for defects & chemistry along & across rod(let) also identifies areas of interest for detailed PIE at INL*
HFEF	*Nondestructive and destructive examination as well as harvest samples of interest for IMCL*
IMCL	*Advanced characterization (additional samples sent to LANSCE, APS, etc for high res examination)*

Assessment and development of advanced ceramic composite fuels

Matrix/2nd Phase (U g/cm^3)	UO_2 (9.7)	U_3O_8 (7.1)	UN (13.5)	U_3Si_2 (11.3)	U_3Si_5 (7.5)	UB_2 (11.7)	UB_4 (7.9)
UO_2 (9.7)	Reference Case	Neutronic	Rxn	Rxn	Rxn	Thermo	Thermo
UN (13.5)	Rxn	Rxn	Rxn	WEC FOA	Thermo / Neutronic	Thermo	Thermo
U_3Si_2 (11.3)	Rxn	Rxn	WEC FOA	WEC FOA	Rxn	Rxn (Thermo)	Rxn (Thermo)
UB_2 (11.7)	Thermo				Rxn (Thermo)		

	Discarded due to reaction with 2nd phase or coolant, and/or neutronics
	Under initial screening
	Viable after initial screening; continuing for further assessment

- Initial screening by neutronics, thermodynamic calculations, and sintered composites
- Systems proposed based upon fissile density, melting point, thermal conductivity, potential for compatibility with standard commercial fabrication infrastructure/expertise
- Constituent phase properties and initial composite material properties will be used as input for Bison allowing modeling-assisted ATF-1 experiment design
- Advanced PIE approach can larger and faster data sets from irradiations

Proposed ATF-1/LANL-1 Fuel Test

Demonstrating a new fuel development paradigm

Model Assisted Design	Measured properties as Bison input for fuel test design
Test Fabrication	LANL pellets to INL for rodlet and capsule fabrication
Pre-test NDE	NDE of as-fabricated capsule (INL→LANL→INL)
Testing	ATR (~10, 20, 40 GWd/MT; first exam in 2016?)
Post-test NDE	*Capsule NDE identifies areas of interest (INL→LANL→INL)*
PIE	*More targeted and more detailed PIE at HFEF*
IMCL, other	*Additional high resolution examination of small samples*

Summary

- **Current ceramic fuel development is focused on enabling ATF development**
  - Separate effects primarily via NEUP
  - Transmutation fuel continuing via PIE and some fabrication and characterization (international collaboration is a key aspect)
- **Coordinated FY15 tasks structured to also advance new fuel development paradigm**
  - Advanced ceramic fuel development (model input, fresh fuel properties)
  - technique development (advanced fabrication, advanced PIE)
  - ATF-1 fuel test fabrication
- **While ceramic fuel development is led by LANL, there is extensive collaboration and coordination**
  - INL, BNL, ORNL, Universities, JAEA, EURATOM